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APPLICATIONS PROGRAM

Technical Report

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Demonstration of an Automatic Meter Reading System in Army Family Housing

by
Lee A. Edgar
U.S. Army Construction Engineering Research Laboratories
Champaign, IL 61826-9005

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Fort Belvoir, VA 22060-5516

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Current Department of Defense (DOD) guidance requires all new and renovated U.S. Army facilities to be equipped with power meters for tracking energy consumption patterns. An increasing number of meters are being installed at Army facilities, but growing manpower constraints are making it difficult for personnel to collect and properly record the data from these meters. An automatic meter reading (AMR) system is one potential way of collecting these data with minimal manpower requirements. As part of the Facilities Engineering Applications Program (FEAP), the U.S. Army Construction Engineering Research Laboratory demonstrated an AMR system for electric meters in the Hess Court family housing area of Fort Benjamin Harrison, IN. The system was found to be capable of meeting industry standards for metering and billing. Technical problems prevented the AMR system from becoming fully operational, however, and insufficient data were collected to confirm the system's effectiveness. Additionally, the system as configured in the test would never pay for itself. Nevertheless, these findings do not rule out the potential usefulness of AMR systems, after reliability and cost issues are addressed by the industry. It is recommended that the Army postpone implementation of AMR systems until the technology is more mature and the power industry approves standards for interconnectivity and quality assurance.

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FOREWORD

This research was performed for the U.S. Army Engineering and Housing Support Center (USAEHSC) under the Facilities Engineering Applications Program (FEAP) Work Unit "Remote Electrical Utility Metering." The USAEHSC technical monitor was H. Goradia, CEHSC-FU-M.

The work was performed by the Energy and Utility Systems Division (FE) of the Infrastructure Laboratory (FL), U.S. Army Construction Engineering Research Laboratories (USACERL). Dr. David M. Joncich is Chief, CECER-FE. Dr. Michael J. O'Connor is Chief, CECER-FL. The USACERL technical editor was Gordon L. Cohen, Information Management Office.

Appreciation is expressed to Michael Leff, Hannon Maase, Daiva Tamulaitis, and Kevin Heyen, CECER-FE, for assistance in performing the tests.

COL Daniel Waldo, Jr., is Commander and Director of USACERL, and Dr. L.R. Shaffer is Technical Director.

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1 INTRODUCTION

Background

The increasing cost of energy has prompted the U.S. Department of Defense (DOD) to provide guidance for Army-wide energy conservation. To meet the new guidelines, energy managers must know how and where the energy is being used. For most Army installations, utility bills for the entire installation are the only source of energy consumption information. These bills usually contain figures for the whole post and are not broken down by area or facility. To address this problem, DOD guidance now requires meters to be installed in all new and renovated facilities.[1]

The growing number of meters provides installation Directorates of Engineering and Housing (DEHs) more information to track energy consumption, but most installations do not have enough manpower available to read most of these meters. An automatic meter reading (AMR) system could solve the problem of manpower constraints by reading large numbers of meters automatically. The information from such systems is kept as digital electronic data so it can be imported and analyzed by computer-based energy reporting programs. This ability to capture and store this information in an electronic format can reduce the number of errors associated with reading meters, recording the data, and transferring it to a computer.

Meter readings collected automatically give DEH personnel a tool for identifying facilities that are using more energy than expected. The information from an AMR system can be used to track a facility's energy use and detect sudden unexplained increases in energy consumption that may signal failing building systems. DEH personnel can use historical data to help determine which facilities would be good candidates for conservation technologies. This historical data could then also be used to accurately calculate the energy savings from conservation retrofits or renovations.

The U.S. Army Construction Engineering Research Laboratory (USACERL) installed and tested an AMR system by Metretek, Inc., at Fort Benjamin Harrison, IN, as part of a Facilities Engineering Applications Program (FEAP) demonstration.

Objective

The objective of this FEAP demonstration was to test a commercially available AMR system on an Army installation to determine system costs and performance.

[1] Military Handbook (MIL-HDBK) 1190, *Facility Planning and Design Guide*, Chapter 13, Sections D.3.b.(4) and D.12.2.,b.,c. (DOD, September 1987).

Approach

This demonstration consisted of the following steps:

1. A commercially available AMR system was selected for testing

2. An Army installation currently reading meters for billing or energy reporting was selected as the demonstration site

3. The AMR system was installed and monitored over time to determine its operational characteristics and costs as compared to manual meter reading.

Scope

This report covers the findings from the FEAP demonstration of the Metretek AMR system in Hess Court at Fort Benjamin Harrison. Due to the short duration of the testing, this report does not cover the system's long-term reliability.

Mode of Technology Transfer

This FEAP project was to result in an Engineer Technical Note and draft guide specifications on automatic meter reading, but these documents were canceled by the sponsor due to equipment problems during the demonstration and the immaturity of the technology. Guide specifications for AMR should await the adoption of interconnectivity and quality assurance standards by the industry.

2 SYSTEM AND SITE SELECTION

System Selection

The selection of the AMR system for this FEAP demonstration was based on previous USACERL research. In that research USACERL evaluated four AMR systems, and the findings were presented in the USACERL technical report *Evaluation of Advanced Single-Phase Electricity Metering Products.*[2] Three of the four AMR systems tested used telephone lines to communicate between the field units and the central computer. Telephone-based systems were selected because the telephone is one of the most mature communication technologies. Telephone lines provide excellent post coverage. Ready access to telephone lines is commonly available, and many installations even own and maintain their telephone exchanges. Of the four products tested, the telephone-based ones provided the best performance. The AMR system manufactured by Metretek, Inc., provided the best performance and lowest cost of the three telephone-based systems tested. Based on its excellent performance in laboratory testing, the Metretek AMR system was selected for this FEAP demonstration.

Site Selection

In order to determine any cost savings from the use of an AMR system, a post that reads meters for billing or energy reporting was required. Adequate telephone service at the site was also necessary since the Metretek system requires access to telephone lines at every metering point. Fort Benjamin Harrison hosts a family housing area called Hess Court, a mobile home park in which the residents are billed for the electricity they use. Hess Court can accommodate up to 100 homes, a number large enough to adequately test the AMR system but not so large as to cause undue logistical problems. Each trailer pad has telephone lines installed, meeting one of the main site selection criteria. Before this FEAP demonstration, installation personnel manually read the meters for billing. Utilities personnel at Fort Benjamin Harrison expressed interest in adapting the AMR system to read gas meters if the technology proved successful.

[2] Richard E. Rundus and Lee A. Edgar, *Evaluation of Advanced Single-Phase Electricity Metering Products*, Technical Report (TR) E-90/04/ADB1448621 (USACERL, April 1990).

3 DESCRIP[illegible]N OF THE METRETEK AMR SYSTEM

Overview

The Metretek AMR system consists of four main components: a pulse initiator, a residential metering unit (RMU), a 300 baud smart modem (SMOD), and AMR system software. The user must supply a personal computer (PC) on which to implement the system. The system is designed to count the rotations of the customer's eddy disk, transmit the infomation to the central computer, and convert the pulse count into useful meter readings. The pulse initiator converts the rotation of the eddy disk to a pulsed output. The RMU counts these pulses and transmits the count to the central computer. The central computer uses a multiplier to convert the pulse count into units of electrical consumption (kiloWatt-hours). The electrical consumption data can then be used for billing or energy consumption reporting.

The four components of the Metretek system are described in more detail below.

Pulse Initiator

The pulse initiator converts rotations of the eddy disk on an induction Watthour meter into pulses. The pulses are transmitted over a wire to the RMU, which counts the pulses.

The pulse initiator consists of a circuit board attached under the eddy disk using the registration plate screw. The circuit board contains two infrared transmitter sensor pairs that detect the passing of a black line on the bottom of the eddy disk. The two sensor pairs are used to detect the direction of the rotation of the eddy disk. If someone tried to reduce their electricity bill by turning their meter upside down, the meter would run backward but the pulse initiator would not generate pulses for counting. In order to generate a pulse, the black line must pass the sensor pairs in the correct order from forward rotation of the eddy disk.

Two sensor pairs are used to eliminate false pulses and increase accuracy. With a single sensor pair, as the line passes the sensor a pulse is generated. When the disk rotates quickly, the sensor pair only has time to generate a single pulse. If the eddy disk is rotating slowly or stops partially covering the sensor, the sensor has ample time to generate a multitude of false pulses. The pulse initiator with the two sensor pairs does not generate a pulse until it receives a matching line-detection signal from both sensors. Even if the line stops over the first sensor pair and prompts several detection signals, a pulse will not be generated until the line passes the second sensor pair. When the eddy disk begins rotating again and the line passes the second sensor, a single pulse is generated. The pulse initiator uses a small 3.6 volt lithium battery for power.

RMU

The RMU is the box mounted at the residence that collects consumption information for transmission to the central computer (Figure 1). The RMU is housed in a grey plastic enclosure with a cover held in place by four screws. When the screws and cover are removed, a single printed circuit board is revealed (Figure 2). A small magnet is attached on the inside of the cover, and a matching magnetic switch is mounted inside the enclosure. When the cover is removed, the magnetic switch is triggered, causing the RMU to report a tamper alarm to the central computer. On the circuit board, the RMU has inputs for up to four pulse initiators. It also has inputs for switches normally open or normally

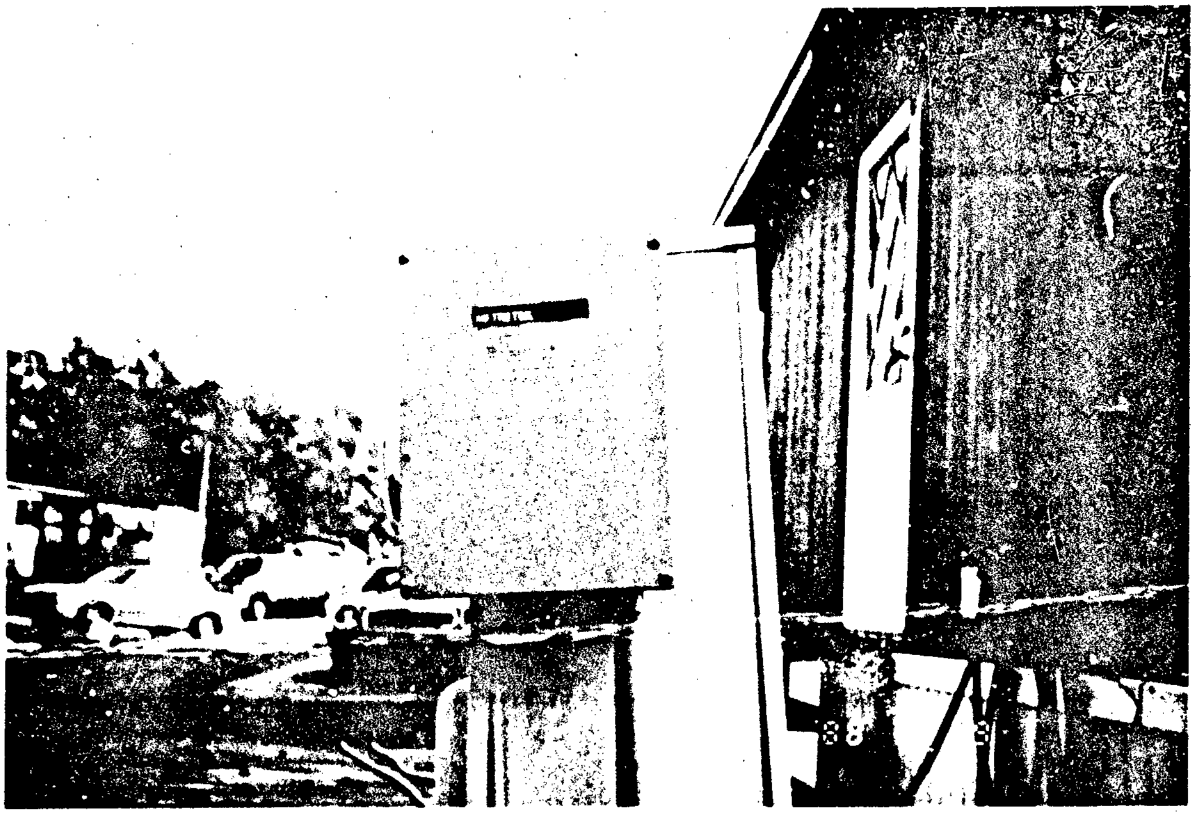

Figure 1. The Metretek RMU.

closed, which can be used to signal alarms. The RMU contains a single board with an integrated telephone modem, pulse totalizer, and other circuits for detecting input switch position.

The board has a socketed programmable read-only memory (PROM) chip that is used to program the characteristics of the RMU. The PROM contains the telephone number of the central computer plus information on how the RMU performs its call-ins, call retries, and alarm calls. The board has a standard RJ-11 jack for connecting to the resident's telephone line and two molex connectors for connecting the lithium battery that powers the RMU. The second molex connector is used when the battery is changed: the new battery is plugged into the open connector before the old battery is unplugged, preventing the RMU from losing information due to the system reset caused by loss of power.

On the upper right-hand corner of the board is a magnetically triggered switch used during checkout of the RMU. When a magnet is passed by the switch, it triggers an alarm that causes the RMU to call the central computer. The magnetic switch allows testing personnel to trigger an alarm sequence from outside the RMU with the cover closed.

SMOD

The SMOD is a 300 baud smart modem used by the central computer to communicate with the RMUs. The SMOD has standard RJ-11C jacks on the back for connecting a voice-grade telephone line. It also has a standard DB-25 connector for attaching the SMOD to the serial port of the central computer. On the front panel of the SMOD is a power switch and a row of lights. These lights provide the user with information on the operation of the SMOD.

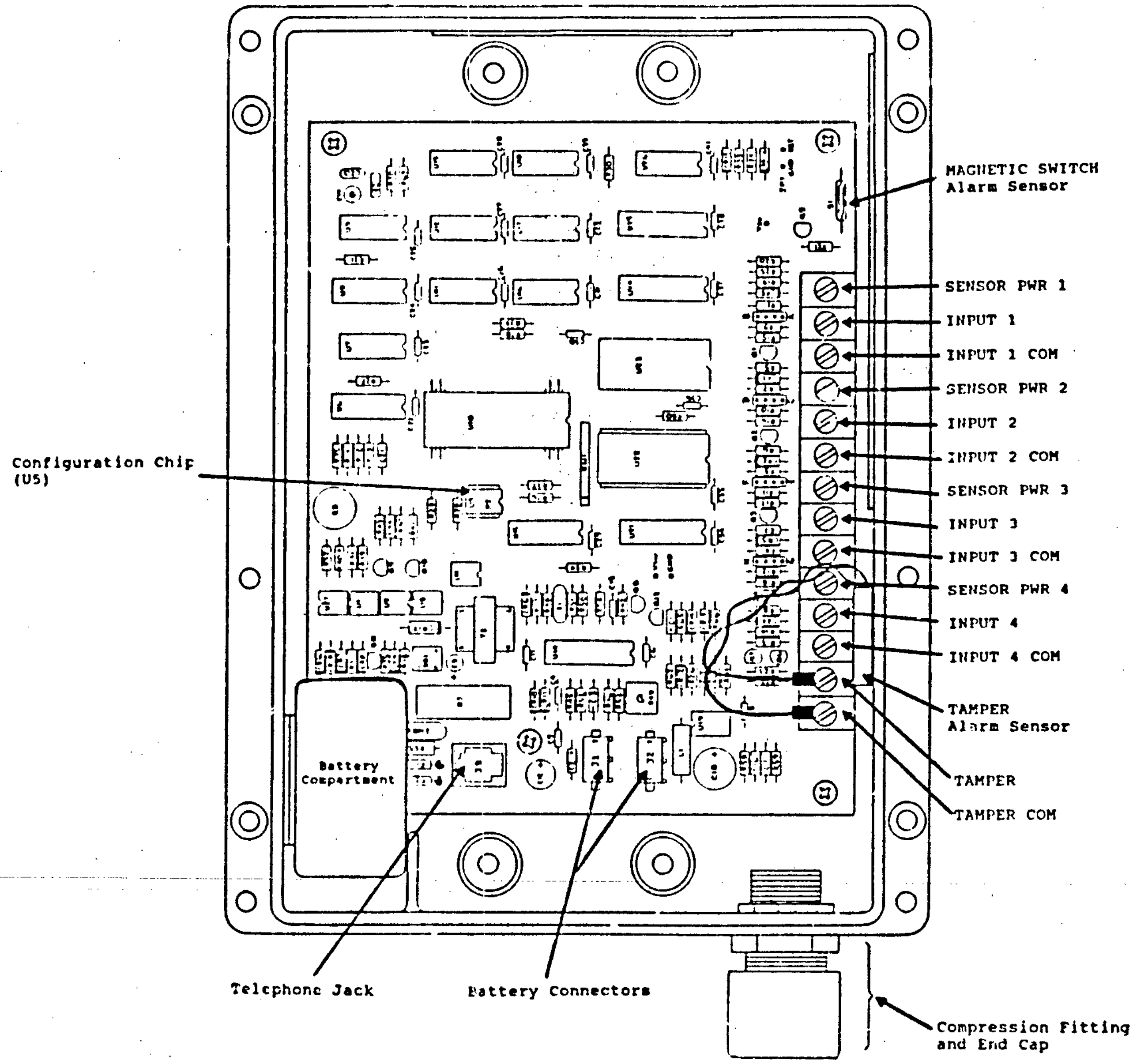

Figure 2. Internal View of RMU.

AMR System Software

The Metretek data collection software is the interface between the user and the meter data. The software consists of several modules, but in this demonstration only three were used extensively: the data collection, data reporting, and display/maintenance modules. The display/maintenance module is used to enter information about the RMU. There are fields to enter the name of the person or business to bill, the account number, and the address. There are several fields for information used to program the RMU. The user can set the call period (time between calls), the date and time of the next call, the use of time-tagged intervals, and meter configuration. Several fields are used by the software to process the pulse data from the RMU. The user must input the meter class, dial count, meter multiplier, meter offset, and meter description. Setting values for these parameters enables the software to work with the basic pulsed data from gas or electric meters.

The data collection module is used to initialize the computer for collecting data from the RMUs. The software waits for the SMOD to detect a call from an RMU, then the software downloads the pulse-count data from the RMU. After the data are collected and stored, the computer uploads the RMU's new programming and the current time to refresh the RMU's clock. The software prints out a log of the call time, date, RMU account number, and any alarm messages (Figure 3). After the log is updated, the software resumes its wait for the next call.

The software's data reporting module was used to print the Meter Reading/Billing Report (Figure 4), which contains the name, address, and account number of the resident to be billed. The report also lists the starting date and ending dates of the billing period, beginning meter reading, ending meter reading, and power consumption for the billing period. In this demonstration the Meter Reading/Billing Report was not directly used for billing. The Fort Benjamin Harrison budget office uses a commercial spreadsheet program to produce bills for installation residents. They took the total consumption numbers from the Meter Reading/Billing Report and entered them into the spreadsheet by hand.

Central Computer

The AMR system tested at Fort Benjamin Harrison was small enough not to require a dedicated PC. This made it possible to load the software on the budget analyst's computer. The budget analyst used the computer as usual during normal working hours and left it in the data collection mode during nonwork hours. The Metretek software requires a substantial amount of disk space—a 30 megabyte (Mb) hard disk is recommended. Metretek also recommends using an AT-class computer, a high density (1.2 Mb) diskette drive, a dot matrix printer, and a tape backup system. The software was installed on an 80286-based PC with a 40 Mb hard drive and 1 Mb of random access memory (RAM). The system ran adequately on this machine, but would have run much faster on a 80386- or 80486-based PC. The hardware used in the demonstration was not strained with only 100 accounts to process.

The central computer requires a dedicated telephone line to communicate with the RMUs. An in-state WATS* line was selected to prevent the residents from having to pay for the calls from their RMU to the central computer. The local telephone company provides measured service, so the residents would have been charged each time their RMU called the central computer.

* WATS: Wide-Area Telecommunications Service.

```
=================================================================================
                         DATA COLLECTION MESSAGES
=================================================================================

01/26/90 14:56:05     SUCCESSFUL SMUD INITIALIZATION BY USER KAY

01/26/90 15:02:40     CALL RECEIVED FROM AIS # 0096

01/26/90 15:02:41     ALARM ON AIS #  0096     EAGAN
                     TAMPER DETECT ALARM
                     CALL RETRY

01/27/90 00:01:40     CALL RECEIVED FROM AIS # 0001

01/27/90 00:04:41     CALL RECEIVED FROM AIS # 0004

01/27/90 00:05:39     CALL RECEIVED FROM AIS # 0005

01/27/90 00:06:41     CALL RECEIVED FROM AIS # 0006

01/27/90 00:07:39     CALL RECEIVED FROM AIS # 0007

01/27/90 00:10:39     CALL RECEIVED FROM AIS # 0010

01/27/90 00:12:39     CALL RECEIVED FROM AIS # 0012

01/27/90 00:13:41     CALL RECEIVED FROM AIS # 0013

01/27/90 00:14:39     CALL RECEIVED FROM AIS # 0014

01/27/90 00:15:39     CALL RECEIVED FROM AIS # 0015

01/27/90 00:16:40     CALL RECEIVED FROM AIS # 0016

01/27/90 00:17:48     CALL RECEIVED FROM AIS # 0017

01/27/90 00:18:40     CALL RECEIVED FROM AIS # 0018

01/27/90 00:19:40     CALL RECEIVED FROM AIS # 0019

01/27/90 00:20:40     CALL RECEIVED FROM AIS # 0020

01/27/90 00:21:40     CALL RECEIVED FROM AIS # 0021

01/27/90 00:21:41     ALARM ON AIS #  0021     DAVIS
                     LOW BATTERY

01/27/90 00:22:36     CALL RECEIVED FROM AIS # 0022

01/27/90 00:22:38     ALARM ON AIS #  0022     LOBSINGER
                     TAMPER DETECT ALARM
                     CALL RETRY
```

Figure 3. Sample Printout of Call Log.

```
09/11/90 06:?.                     METER READING / BILLING REPORT (01.06)                           PAGE  1

CUSTOMER ACCOUNT  :   LOT 1                       AIS NUMBER   :   0001     ACTIVE
         NAME     :   CAPRON
         COUNTY   :   COUNTY                      CONFIG       :   1 INPUT RMU
         ADDRESS  :   ADDRESS
         CITY     .   CITY                        LAST CALLED  :   09/04/90 00:01
         STATE    :   ST          ZIP
         PHONE NO :   PHONE NO

                   REPORT PERIOD: FROM 08/01/90 00:00 UP THRU 09/07/90 00:00
```

SERIAL #	INPUT #	START DATE/TIME	START READING	END DATE/TIME	END READING	TOTAL CONSUMPTION	UNITS OF MEASURE
SERIAL_NO	1	08/05/90 00:01*	37221.05	09/04/90 00:01*	38552.33	1331.28	KWH
						1331.28	

```
CUSTOMER ACCOUNT  :   LOT 2                       AIS NUMBER   :   0002     ACTIVE
         NAME     :   AUSTIN
         COUNTY   :   COUNTY                      CONFIG       :   1 INPUT RMU
         ADDRESS  :   ADDRESS
         CITY     :   CITY                        LAST CALLED  :   09/04/90 00:02
         STATE    :   ST          ZIP
         PHONE NO :   PHONE NO

                   REPORT PERIOD: FROM 08/01/90 00:00 UP THRU 09/07/90 00:00
```

SERIAL #	INPUT #	START DATE/TIME	START READING	END DATE/TIME	END READING	TOTAL CONSUMPTION	UNITS OF MEASURE
SERIAL_NO	1	08/05/90 00:02*	18811.76	09/04/90 00:02*	20053.62	1241.85	KWH
						1241.85	

Figure 4. Meter Reading/Billing Report.

Basic System Operation

Normal system operation begins at the pulse initiator. The pulse initiator converts the revolutions of the meter's eddy disk into electrical pulses. The pulses are sent through a wire to the RMU, where the pulse count is stored. The RMU continues to track the pulse count until its internal clock matches the call time the unit received at its last call to the central computer. The RMU picks up the telephone line to determine if it is being used by the resident. If the RMU detects that the telephone is being used, it immediately drops the line and tries again later. If the line is free, the RMU begins to dial the telephone number stored in the PROM. If the RMU receives a busy signal, it hangs up and calls again later. When the central computer answers the call, the RMU begins to download its pulse count and any alarms it may have detected. The central computer stores the RMU data and transmits any new programming to the RMU, as well as the new call time and date. After receiving the new programming, the RMU hangs up and returns to counting pulses. The central computer updates the printer log with the time, date, RMU account number, and any alarms detected (as shown in Figure 3).

If the resident picks up the telephone while the RMU is transmitting data, the RMU will immediately relinquish the line to the resident and call the central computer later. In such cases, the central computer ignores any partial data transmission. The amount of time the RMU waits to retry the call is programmed into the RMU's PROM.

Alarm Calls

Certain situations can trigger an alarm that prompts the RMU to call the central computer immediately (e.g., system reset, open door, magnetic switch alarms). The low battery alarm is reported during normally scheduled calls. The system reset alarm indicates that the RMU has been restarted and requires programming. When RMUs are first installed they report this alarm. The open door alarm indicates that the RMU has been opened and could be tampered with. The magnetic switch alarm indicates that a strong magnet has been placed near the RMU in a possible attempt to affect its accuracy.

4 INSTALLATION

Pulse Initiator

The pulse initiators were mounted on General Electric form 2S, class 200 meters using the registration plate screws (Figure 5). Before the pulse initiator was attached, a black line 0.5 in. (12.7 cm) wide was painted across the bottom of the eddy disk. Once the unit was mounted, two wires from the onboard transformer were soldered to the top two lugs of the meter. A small hole was drilled in the rear meter housing so the pulse initiator cable could be strung out the back. Once the cable was run out the hole, silicone caulk was used to seal the hole around the cable. The displaced registration plate was glued to the inside of the clear plastic front cover. When the front cover was installed on the meter properly, the registration plate appeared to be in its regular position.

RMU Installation

The RMUs were mounted to the freestanding meter pedestals by each trailer pad. Five holes were drilled in the back of the RMU: four were used for attaching screws, and the fifth was used to pass the pulse initiator cable into the RMU enclosure. The pulse initiator cable was run out the back of the meter, and through the pedestal to the RMU attachment point, then out through a hole in the pedestal and into the RMU enclosure through the fifth hole drilled in its back (Figure 6). After the cable was strung, the RMU was attached to the pedestal with four sheet metal screws. The pulse initiator cable was attached to the terminals in the RMU. A PROM preprogrammed to USACERL specifications by Metretek was installed in its socket.

The cable connecting the RMU to the resident's telephone service was run out the lower right-hand corner of the RMU where a plastic conduit is attached. The conduit carried the cable down and underground, then back up to the telephone network interface (TNI) box (Figure 7). The cable was attached to the terminals inside the TNI box on the resident's side. Inside the RMU, the other end of the cable was wired to an RJ-11 telephone jack. A short telephone cable with RJ-11 connectors on both ends was plugged into the telephone jack and the RJ-11 socket on the RMU's circuit board. When the battery was plugged into the molex connector on the circuit board, the RMU began operating. The installer recorded the time and the meter reading on a list that was used later to program the central computer.

Central Computer Setup

The central computer did not require much hardware setup since the machine was already set up to handle budgeting chores (Figure 8). The SMOD was attached to the PC's COM1 serial port, and the WATS line was plugged into the SMOD. The computer already had a dot matrix printer attached to the LPT1 parallel port. The AMR system software was installed by one of Metretek's technicians. Installation consisted of loading software from 13 diskettes onto the computer's hard drive and setting up a file to hold the metering data. Once the software was installed, meter accounts for all participating residents had to be set up. Information about the resident and his or her meter was input into the computer, including the resident's address and the type of meter generating the pulsed data. After the first call from all RMUs, a list of the residents' current meter readings was keyed into the central computer. With this information the computer would use the pulsed data called in by the RMUs during each billing period to calculate the actual meter reading.

Meter Calibration

After the pulse initiators were retrofitted to the meters, they were recalibrated to ensure accurate readings. A contractor was retained to recalibrate the meters. Accurate readings were required since Family Housing would be using the meter readings for billing. Figure 9 shows a sample of the meter test cards used to record calibration information. The card records both the original accuracy of the equipment and its accuracy after calibration.

Figure 5. Pulse Initiator Mounted on Electric Meter.

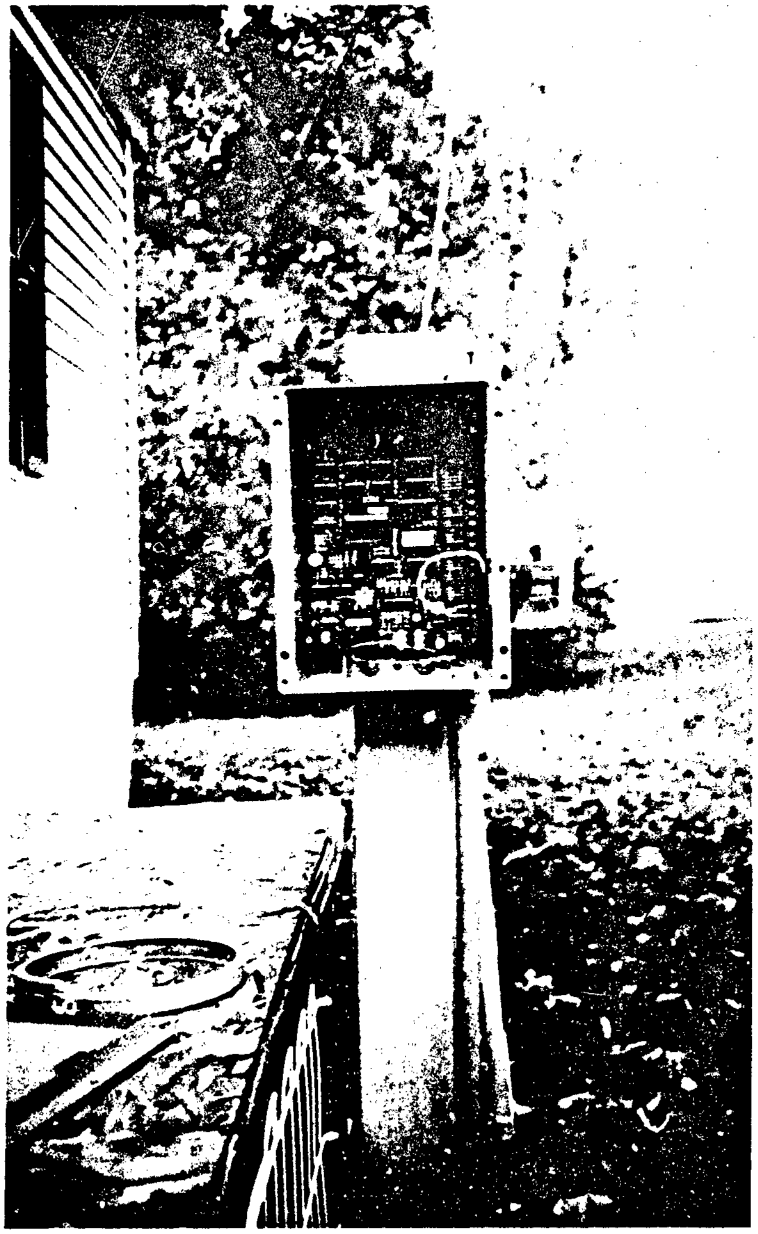

Figure 6. RMU Connections.

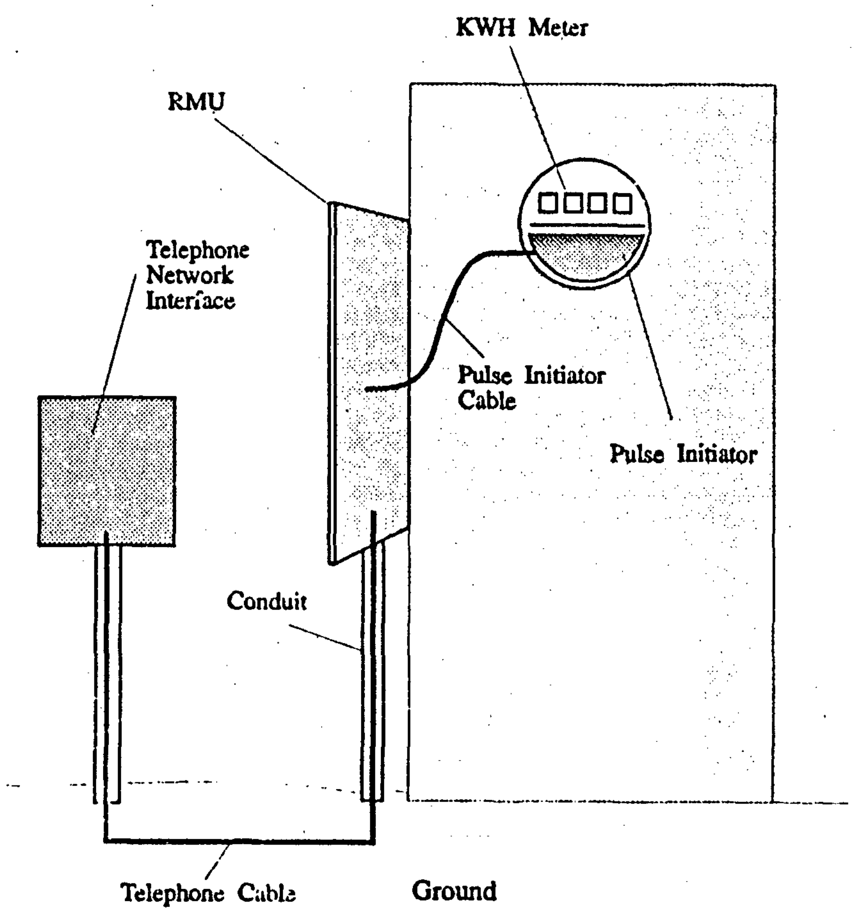

Figure 7. Installation Schematic.

Figure 8. Central Computer Hardware and Peripherals.

ELECTRIC LABORATORIES AND SALES CORPORATION

CUSTOMER: Timothy O. Capron #1

METER TEST CARD

Date: 6-12-89 Onr: C L

Company #:

Test Type: — Gear Ratio: 1388 8/9

Mfgr: GE

Serial #: 81 716 875

Type: I-70-S

Demand: —

Reg K AF: 10 AL: 10

Sec K: 7.2

Volts: 240 Amps: 30

Phase: 1 Wire: 3

METER TEST RESULTS	AS FOUND	AS LEFT
LL %	99.6	100.0
FL %	99.5	100.0
Avg %	99.5	100.0
Seal #	No Seal	55
KWH Reading	07597	07597
Creep	No	No

COMMENTS:

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Figure 9. Meter Calibration Test Cards.

5 AMR SYSTEM OPERATION

Problems with the AMR system began surfacing immediately after installation was complete. After software installation the Metretek technician toured Hess Court to view the installed RMUs. He noted that the wrong enclosures had been used for mounting the RMUs outdoors. The system USACERL tested previously had included plastic enclosures. About the time that the equipment for this demonstration was ordered, Metretek eliminated the weatherproof door seal from the plastic enclosures and designated them for indoor use only. Company personnel filling USACERL's order assumed that the equipment was to be installed inside the meter pedestals. Rather than install the more costly steel outdoor enclosures offered by Metretek, the researchers retrofitted the plastic RMU enclosures with weatherproof gaskets provided by the company.

Early accuracy testing of the AMR system showed that the system was providing incorrect meter readings. The problem was determined to be in the pulse initiators. All meters with pulse initiators had to be returned to Metretek for repair. After the pulse initiators were repaired, the meters were reinstalled and testing proceeded.

Accuracy testing of the AMR system continued, but the system was plagued with a high failure rate. The accuracy checks were performed at monthly intervals, and the failure rate was near 80 percent. The RMUs were locking up, and had to be restarted by interrupting the battery power supply. When the RMUs were restarted, the PROM settings in some of them were altered or missing completely. Metretek provided capacitors to protect the PROMs and prevent lockups. The company also provided new PROMs to replace the damaged ones. When the capacitors were installed, the failure rate dropped to 50 percent—still unacceptably high.

The RMU failures generally occurred within a few weeks. Close examination of the RMUs showed traces of moisture. The gaskets provided adequate sealing, but moisture was still penetrating the enclosures by traveling up the conduit and into the RMUs. The conduits were then sealed with duct-sealing clay. At the same time, desiccant packs were taped inside the enclosures in an effort to rid the RMUs of moisture. Humidity sensor cards were installed in the RMUs to track the moisture levels. With these retrofits in place, the failure rate fell to under 5 percent.

As the AMR system began to operate for periods longer than a month, problems with residents' telephone service cropped up. The RMUs use a pulse dialing modem to call the central computer. Pulse dialing can cause telephones with electronic ringers to ring softly. The RMUs were originally scheduled to call starting at midnight. Several residents expressed irritation at the ringing of their phones at 2 a.m. These RMUs had to be reprogrammed to call during the afternoon while the affected residents were at work. The RMU's pulse dialing also caused a similar problem with an answering machine at one residence. Every time the RMU would try to call, the answering machine would detect the pulses, interpret them as ringing, pick up the line, and record the RMU trying to transmit its data to the central computer. Apparently this was more a problem with the answering machine than with the Metretek system, however; when the resident exchanged the answering machine for an identical unit, the problem ceased.

There were several other problems related to the telephone service. One resident did not have telephone service so his meter had to be read manually. Also, Hess has a high level of residential turnover, with people continuously moving in and out. Frequently, residents would have their telephone service disconnected before moving out, so the meter had to be read manually for the final bill. Also, residents moving in would often move the TNI box to suit themselves, which required installation of a new cable to reconnect the RMU. Generally, once or twice a month, the researchers had to reconnect the

equipment or install new cable. This would not normally be a problem if you were metering buildings or houses.

Several other problems had a negative impact on the effectiveness of the AMR system. At the beginning of January 1990, the WATS service stopped operating. The RMUs were unable to reach the central computer with their monthly call. Due to this problem, all meters in Hess Court had to be read manually. A side effect of this problem was excessive wear on the RMU batteries as the units tried repeatedly to connect with the central computer. It took several days for Indiana Bell to repair the WATS service. Finally, 1 week after the WATS service was repaired, the central computer suffered a hard drive failure. It took several weeks to repair the computer, reinstall the software, and reprogram the metering and billing information.

6 SYSTEM EVALUATION

Data Collection

Power consumption data were collected from Hess Court roughly every 30 to 45 days. Data were recorded manually at Hess Court from the meters and automatically over the WATS line by the AMR system. The actual meter readings were recorded along with the time that the readings were taken. Using a magnet to trigger the magnetic switch alarm described earlier, the researchers forced the RMUs to call the central computer with their pulsed data and the times at which those data were recorded. If the time of a call by the RMU differed from the time of a manual meter reading by more than 5 minutes, that meter was reread. If the reading calculated by the central computer differed from the actual meter reading by more than 10 kiloWatt-hours, the computer's reading was reset to match the actual meter reading.

The period from 20 April 1990 to 14 November 1990 represents the longest continuous period during which data were collected. (Note that the data for September are included in the October reading due to the meter reading schedule. There is no gap in the data.) Data collected during this period are presented in the Appendix.

The tables for each data collection period list the account number (which matches the lot number), the reading from the meter, and the reading from the Metretek AMR system for each lot in Hess Court. The zeros in the tables represent lots where the system was not operational. Several lots were not operational because they were vacant. Lot 70 remained vacant the entire time the system was installed in Hess Court.

Accuracy

The accuracy of the Metretek AMR system was determined by calculating the percent difference between the monthly consumption calculated using values from the AMR system and consumption calculated from the actual meter readings. Specifically, the difference is calculated using the following formula:

$$PD = (1 - ((K_2 - K_1)/(M_2 - M_1)) * 100 \qquad [Eq\ 1]$$

where PD = percent difference
K_2 = Current Metretek meter reading
K_1 = Previous Metretek meter reading
M_2 = Actual meter reading
M_1 = Previous actual meter reading.

The average percent difference, APD, for the entire data collection period was calculated by summing the absolute value of each monthly percent difference, ABS(PD), and dividing by 5. The formula used is as follows:

$$APD = (ABS(PD_1) + ABS(PD_2) + ABS(PD_3) + ABS(PD_4) + ABS(PD_5))/5 \qquad [Eq\ 2]$$

The monthly and average percent deviations are listed in Table 1. The table is sorted by the average percent deviation in ascending order. Figure 10 plots the top 10 accounts from Table 1 those that have deviations of about 0.2 percent or lower and fall within acceptable limits for meter calibration in the field. Of all AMR accounts listed in Table 1, 34 had average deviations of less than 2 percent, which is the

Table 1

Percent Deviation Between AMR and Actual Readings

Account Number	April May	May June	June August	August October	October November	Average % Deviation
23	0.06	0.01	0.01	-0.02	0.01	0.02
89	0.04	0.01	0.06	0.02	0.08	0.04
14	0.03	0.04	0.03	0.00	-0.11	0.04
68	-0.04	0.04	-0.04	-0.07	-0.19	0.07
15	0.12	0.05	0.02	-0.12	-0.11	0.09
52	0.31	0.14	-0.05	-0.01	-0.03	0.11
2	0.00	0.33	-0.02	0.04	-0.06	0.11
5	0.15	0.14	-0.17	0.08	-0.17	0.14
25	0.21	0.13	-0.02	-0.06	-0.56	0.19
7	0.17	0.21	0.24	0.08	-0.03	0.21
36	0.55	0.12	0.03	-0.20	-0.23	0.23
61	-0.19	0.55	-0.06	0.31	-0.01	0.23
21	0.28	0.03	-0.03	-0.30	-0.52	0.23
64	0.20	0.01	0.02	-0.14	-0.82	0.24
54	0.44	-0.06	-0.16	-0.02	-0.70	0.26
29	-0.54	-0.21	0.09	-0.01	-0.72	0.31
65	-1.14	-0.56	-0.03	0.08	0.04	0.37
49	0.42	-0.32	-0.69	0.58	-0.04	0.41
67	0.37	-0.51	-0.38	-0.08	0.75	0.42
39	-0.03	1.46	-0.57	0.16	0.04	0.45
20	0.02	0.02	-0.16	1.03	1.29	0.50
46	-0.46	0.16	-0.02	-0.11	2.34	0.62
31	0.13	0.21	-0.11	1.12	1.78	0.67
16	1.92	-0.04	-0.65	0.71	-0.04	0.67
55	1.26	-1.63	-0.25	0.53	-0.07	0.75
3	0.79	0.00	0.02	-0.05	-3.39	0.85
69	-2.25	-6.68	-1.39	1.22	1.60	1.43
62	-4.94	-0.33	-0.03	-0.10	1.89	1.46
41	-0.25	-1.75	-1.48	1.65	2.16	1.46
27	-0.37	1.61	-0.73	0.26	-5.03	1.60
73	-0.43	-2.68	1.88	-1.91	1.13	1.60
75	-2.04	1.26	4.63	0.13	0.55	1.72
74	0.46	-2.47	0.55	-0.19	-5.87	1.91
63	0.11	-0.10	-0.07	-0.13	9.28	1.94
58	-6.59	-3.29	-0.04	0.06	-0.95	2.01
71	1.20	-0.27	-0.23	3.55	6.07	2/26
59	1.54	0.09	0.30	6.26	3.86	2.41
60	0.00	-0.13	-0.09	6.28	6.29	2.56
50	-0.18	-0.00	-0.01	-0.03	-15.29	3.10
13	0.19	0.05	4.26	-6.09	8.48	3.81
10	-0.13	0.33	4.06	-13.53	1.57	3.92
40	2.07	-0.21	-0.42	-20.05	-0.03	4.55
56	0.22	0.38	0.12	29.49	0.05	6.05
83	32.02	-0.06	-0.29	-0.26	-0.10	6.55
87	33.02	0.58	-0.71	0.46	1.31	7.22
44	-25.33	9.10	-0.47	1.54	-0.56	7.44
100	38.06	0.21	-0.21	-0.03	-0.02	7.71
19	3.19	-2.51	-0.08	-1.12	-32.44	7.87
97	44.26	0.80	-0.32	0.48	0.00	9.17
47	8.12	40.14	-10.87	2.06	-0.09	12.26

Table 1 (Cont'd)

Account Number	April May	May June	June August	August October	October November	Average % Deviation
9	31.70	-26.63	-0.32	0.15	-3.69	12.50
45	17.98	-6.25	-10.24	-0.37	31.25	13.22
85	63.62	-0.92	-1.00	1.36	-0.01	13.38
98	78.14	-0.22	-0.12	-0.27	0.05	15.76
77	85.39	-1.57	-0.39	2.44	-0.21	18.00
24	0.25	-0.14	0.03	-0.05	-116.35	23.37
82	26.43	0.00	-0.02	0.01	96.99	24.69
81	32.03	0.03	0.00	-0.07	103.51	27.13
43	-0.04	-0.14	-0.07	60.87	79.03	28.03
66	0.11	0.24	4.17	-7.07	-137.71	29.86
42	100.00	-96.11	-0.15	0.02	5.94	40.44
51	78.75	11.00	-46.18	102.76	0.12	47.76
12	53.98	42.13	74.95	-99.36	8.96	55.87
96	-91.61	32.95	66.79	-144.85	-3.91	68.02
48	-0.09	17.70	638.68	-1120.90	7.13	356.90
34	-71.17	14.30	85.61	-1698.00	-3.22	374.66
4	0.02	0.02	-0.08	2017.97	0.27	403.67
90	-843.67	-70.74	-568.66	1270.28	-0.24	550.72
22	-0.05	-3063.39	-8.53	1416.39	-0.88	897.85
1	0.08	-0.07	-0.04	0.00	24207.49	4841.53
8	0.08	-0.20	0.21	0.05	N/A	N/A
57	-0.25	-0.47	0.23	0.08	N/A	N/A
26	0.66	-0.83	-0.14	-0.17	N/A	N/A
11	-1.58	1.06	-0.13	-0.13	N/A	N/A
53	78.11	14.60	60.98	-80.17	N/A	N/A
38	-2.54	34.61	100.00	-197.83	N/A	N/A
6	51.54	7.84	1283.59	-1768.51	N/A	N/A
37	14144.7	-1.52	1.20	1.94	N/A	N/A
17	N/A	-4.84	-0.17	-0.08	N/A	N/A
18	N/A	-5.27	2.48	-5.05	N/A	N/A
28	N/A	N/A	N/A	N/A	N/A	N/A
30	-0.02	N/A	3.25	-72.24	N/A	N/A
32	N/A	N/A	N/A	N/A	N/A	N/A
33	N/A	-12.63	3.20	-0.67	N/A	N/A
35	N/A	-1.58	-0.56	0.91	N/A	N/A
70	N/A	N/A	N/A	N/A	N/A	N/A
72	N/A	-87.63	0.38	-1.74	N/A	N/A
76	N/A	N/A	N/A	N/A	N/A	N/A
78	N/A	N/A	N/A	N/A	N/A	N/A
79	N/A	N/A	16.50	-211.33	N/A	N/A
80	27.62	27.62	-1.03	1.92	N/A	N/A
84	N/A	N/A	N/A	N/A	N/A	N/A
86	N/A	N/A	N/A	N/A	N/A	N/A
88	28.94	0.00	N/A	-0.02	N/A	N/A
91	N/A	N/A	N/A	N/A	N/A	N/A
92	N/A	30.75	-0.54	8.47	N/A	N/A
93	N/A	N/A	N/A	N/A	N/A	N/A
94	N/A	N/A	N/A	N/A	N/A	N/A
95	N/A	11.89	100.00	-239.68	N/A	N/A
99	N/A	0.00	-0.01	N/A	N/A	N/A

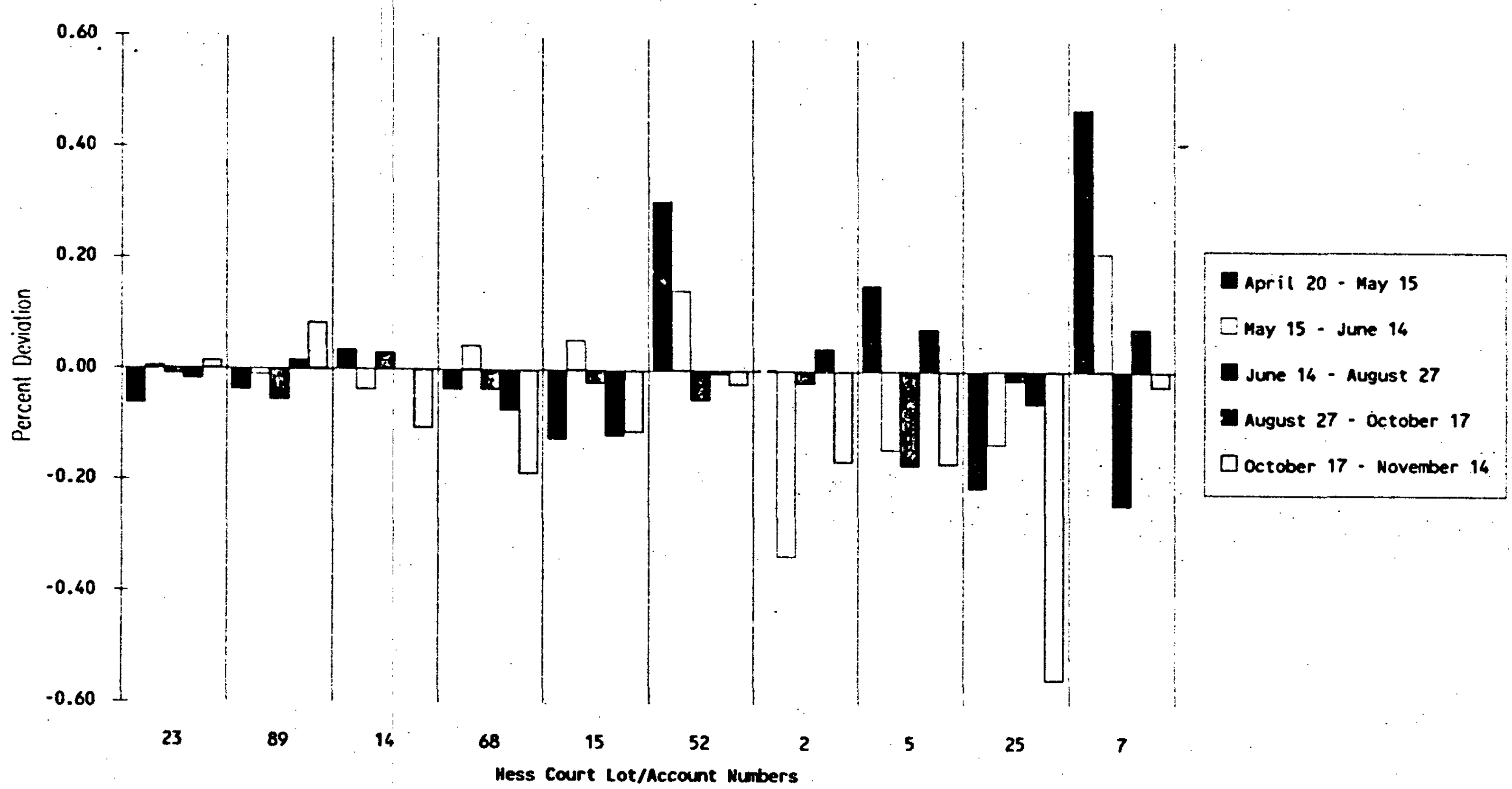

Figure 10. Ten Most Accurate AMR Accounts.

maximum margin of error for billing purposes considered acceptable within the industry.[3] These data show that the Metretek AMR system is indeed capable of providing meter readings accurate enough for billing purposes. However, due to the technical problems previously cited, 66 of the 100 AMR accounts were not served with the required level of accuracy. Furthermore, thirty of these did not even have enough data to calculate a meaningful average due to lots being vacated or RMU failure.

Costs

The cost of the Metretek AMR system is compared to the cost of reading the meters manually in Table 2. The system will never pay for itself due to the cost of the WATS service charge. Even if the WATS line was not used, the payback would still exceed 50 years. The installed per-point cost for this system is $576, and the cost to manually read a single meter for an entire year was $12. In order for a system to provide paybacks shorther than 10 years, the installed per-point costs would have to be reduced to under $120. The per-point installation charges for the Metretek system exceeded $240. Even if the Metretek equipment were donated free of charge, it would still not be possible to get a payback of less than 20 years due to the high installation cost.

Table 2

Cost of Metering for Hess Court

Monthly Operations		Cost
Manual reading (4 man-hours/ for 100 meters)		$100
Metretek AMR (WATS charge/ month for 100 meters)		$130
Equipment and Installation*	**Per Point Cost**	**Total Cost (100 units)**
RMUs	$225	$22,500
Pulse initiators	45	4,500
SMOD (300 baud)**	10	1,000
Software, training	15	1,500
AMR installation	240	23,980
TNI boxes, installation	41	4,100
GRAND TOTALS	$576	$57,580

* Costs of retrofitting and troubleshooting are not included. Since these coats would be unnecessary with a fully functioning system, they were accounted for under testing costs. Equipment and installation costs apply to AMR system only; no equipment or installation were required to support manual meter reading.

** Does not include cost for central computer. Test used existing PC after business hours.

[3] American National Standards Institute (ANSI) Standard C12.1-1988, *Electricity Metering* (ANSI, 31 March 1989), p 141.

7 CONCLUSIONS AND RECOMMENDATIONS

The FEAP demonstration of the Metretek AMR system at Hess Court, Fort Benjamin Harrison, provided information on both the performance of the Metretek system and the commercial telephone system as the communications medium for transmitting metering data.

On first examination the telephone system would seem to be an excellent medium for enabling the automatic collection of family housing power consumption data. However, there are problems with this approach. Although the telephone is the most well established electronic communications technology, there are still residents without telephone service. Therefore, the power consumption of these people could not be tracked with the AMR in this test. Obviously, this problem would have to be addressed in any permanent implementation of AMR for family housing. Also, this test revealed a problem with pulse-dialing RMUs such as Metretek's: pulse dialing apparently triggers a slight ringing of the residents' telephone sets when the RMU is calling in data to the central computer. This nuisance factor makes pulse dialing systems unsuitable for Army family housing applications. If Metretek upgraded its RMUs to use tone dialing, this problem would be eliminated. One other telephone-related factor proved to be a problem in this test: reliance of the system on WATS service. WATS was used to avoid having the power customer pay for the monthly telephone call from the RMU to the central computer. This built an overhead cost into the system that could never be recouped, because WATS service alone cost 30 percent more per point than manually reading the meters. A better approach in future tests and applications might be to use the customers' telephone service, but issue them a credit on each bill to offset the cost of the call from the RMU.

In terms of its metering performance, the Metretek AMR system was accurate enough to meet industry standards in a significant percentage of cases. However, the test was seriously impaired due to equipment installation and reliability problems, and, for this reason, adequate data to confirm the system's effectiveness were not produced. In terms of its cost effectiveness, the Metretek system as currently priced offers no practical payback period when compared to the cost of manually reading power meters. It should be noted that neither the technical nor the cost problems experienced in this test need rule out AMR as a viable alternative to manual meter reading. If Metretek can improve the reliability of its pulse initiators and significantly decrease system costs, the company's AMR system might become a cost-effective tool for the Army. Additionally, the cost effectiveness of AMR systems in general is likely to improve simply as an effect of future Army personnel constraints: the time and manpower costs of reading meters manually are certain to rise as these constraints are implemented.

It is recommended that the Army postpone implementation of AMR systems until the technology is more mature. The technical problems in setting up and operating the test system highlight a larger problem that extends beyond any one company: the lack of industry standards for interconnectivity and quality assurance. Until industry standards emerge, the Army can implement AMR only at the cost of being captive to a single vendor. When standards are accepted by the industry and multiple products that meet these standards are available, the Army should be able to implement AMR systems made up of components from more than one vendor. If industry standards promote true component interoperability, industry competitiveness may improve as more manufacturers enter the market. Manufacturers will be freer to specialize in single components rather than supporting a whole proprietary system. It is reasonable to assume that such developments would help reduce the costs and improve the quality of AMR technology.

The future of AMR in the Army will be driven by metering, energy management, and manpower goals. Based on the changing environment and priorities for using resources, the need for cost effective AMR systems will increase with new initiatives to track energy consumption, reduce utility bills, and fulfill manpower allocation requirements.

APPENDIX: AMR System and Actual Meter Readings, April-November 1990

Meter Readings for April 20, 1990

Account Number	Meter	Metretek	Account Number	Meter	Metretek
1	32873	32875.78	51	20292	22532.65
2	14963.5	14963.8	52	52613.5	52615.86
3	34192.1	34198.38	53	30341	30271
4	21597.6	21597.46	54	32824	32827.51
5	13074	13077.37	55	11762	11776
6	21491	21913.65	56	4210	4210.47
7	7702	7702.48	57	8828	8828.14
8	1828	1828.1	58	45937.5	45393.5
9	9787.4	9787.31	59	9047.5	9049.29
10	38360	38359.09	60	16665	16665.32
11	2721	2721.24	61	1831.5	1832.36
12	9169	9164.66	62	14861	14827.25
13	88460.6	88460.2	63	13414	13415.31
14	46727	46728.32	64	31913.75	31915.19
15	30304	30304.92	65	13880.25	13879.05
16	7981	7983.01	66	33823.5	33824.56
17	11658	11599.56	67	12638	12640.15
18	2965.3	2958.48	68	17353.5	17354.97
19	6171	6169.85	69	17515.5	17516.32
20	5595.2	5595.6	70	0	0
21	10012	10012.37	71	6643.5	6643.36
22	39087	39087	72	6888.5	6688.42
23	20731	20731.63	73	6833.1	6833.07
24	34348	34352.26	74	4182.5	4182.91
25	19642	19642.04	75	9422.5	9422.46
26	5798	5798.4	76	0	0
27	1853	1852.79	77	2226	2300.29
28	0	0	78	0	0
29	753	751.6	79	0	0
30	39804	39812.78	80	971	1032.57
31	2684.1	2684.92	81	17395	17684.87
32	0	0	82	13372.75	13586.11
33	32725	32640.5	83	15997.75	16281.79
34	32095	609.08	84	0	0
35	20298.6	20301.4	85	2153	2199.17
36	12084	12087.63	86	0	0
37	529	7602.1	87	7903.25	7922.23
38	4382.5	4381.07	88	9884.9	9903
39	8797	8797.14	89	74287	74287.25
40	9387	9387.45	90	8153	8223.48
41	7856	7856.6	91	0	0
42	7778	7779.57	92	2276.75	2356.59
43	11887	11888.04	93	0	0
44	4902	4890.39	94	0	0
45	15703.5	16097.72	95	0	0
46	15931	15929.53	96	16333.5	15052.07
47	8121	8090.71	97	19617	19971
48	17240	17240.32	98	34998.5	35725.11
49	17438	17434.56	99	12045	12046.99
50	20917	20918.04	100	11392	11634.36

Meter Readings for May 15, 1990

Account Number	Meter	Metretek	Account Number	Meter	Metretek
1	34086	34087.82	51	21220.5	22729.92
2	15942.5	15942.78	52	53517.5	53517.1
3	35077	35076.26	53	31203	30459.65
4	22413.5	22413.22	54	33801	33800.17
5	13753.5	13755.82	55	12243	12250.95
6	22178.5	22246.78	56	4319	4319.71
7	7793	7793.05	57	8911	8911.35
8	1907	1907.04	58	47293.5	47338.83
9	10460.5	10247.03	59	9155	9155.13
10	39668	39668.77	60	17703.75	17704.07
11	2797	2798.44	61	1937	1938.06
12	9210	9183.53	62	15513	15511.46
13	89556	89557.7	63	14209	14209.4
14	47536	47537.04	64	32585.5	32585.58
15	31764	31766.74	65	14493.5	14499.28
16	8055	8055.59	66	34655.5	34657.45
17	11658	11599.56	67	12938.5	12961.85
18	2965.3	2958.48	68	18344	18345.83
19	6285	6287.5	69	18415	18436.05
20	5653.5	5653.89	70	0	0
21	10848	10850.76	71	6782	6780.2
22	39848	39848.41	72	6888.5	6688.42
23	21855.5	21856.89	73	6971	6971.56
24	35548.5	35549.75	74	4232.5	4232.68
25	20630.5	20632.62	75	9496	9497.46
26	5893.5	5893.27	76	0	0
27	1888.5	1888.42	77	2313	2313
28	0	0	78	0	0
29	1023.5	1023.57	79	0	0
30	0	0	80	971	1032.57
31	2756	2756.73	81	18304	18302.7
32	0	0	82	14182	14181.45
33	32725	32640.5	83	16887	16886.3
34	33017	2187.23	84	0	0
35	20298.6	20301.4	85	2225	2225.36
36	12674	12674.4	86	0	0
37	579	579.73	87	7962	7961.58
38	4508.5	4510.27	88	9947	9947.13
39	8884.5	8884.67	89	75496	75496.71
40	9460.5	9459.43	90	8268.5	9313.42
41	7915	7915.75	91	0	0
42	7832	7779.57	92	2276.75	2356.59
43	12494	12495.29	93	0	0
44	4997	5009.64	94	0	0
45	16453	16712.43	95	0	0
46	16527	16528.3	96	17002.5	16333.93
47	8604	8612.93	97	20403.5	20409.43
48	18014.5	18015.54	98	35926	35927.87
49	18510.5	18522.48	99	12045	12046.99
50	21553.5	21555.67	100	12032	12030.78

Meter Readings for June 14, 1990

Account Number	Meter	Metretek	Account Number	Meter	Metretek
1	35188	35190.57	51	22448	24092.5
2	16948	16951.64	52	54631.5	54629.5
3	36004.5	36003.76	53	32223.5	31331.16
4	23445	23444.48	54	35003	35002.86
5	14553	14556.46	55	12824	12841.42
6	22768	22790.06	56	4455	4456.23
7	7901	7900.82	57	9008	9008.81
8	2009	2009.24	58	48663	48663.22
9	11232	11223.98	59	9248.5	9248.55
10	41000	41005.23	60	19053.5	19055.58
11	2925	2925.08	61	2058	2058.39
12	9266	9215.94	62	16465	16466.61
13	90741	90742.1	63	15343	15342.32
14	48549	48550.42	64	33472	33471.99
15	33552.5	33554.28	65	15292	15293.28
16	8129	8129.62	66	35532	35531.89
17	12945	12948.91	67	13311	13316.16
18	3072.5	3071.33	68	19402	19403.37
19	6400.5	6400.1	69	19691	19720.79
20	5718.5	5718.88	70	0	0
21	11941	11944.08	71	6948	6946.65
22	40780	69331.19	72	7117	7117.15
23	23115	23116.32	73	7125	7129.68
24	36927.75	36930.92	74	4297	4298.77
25	21914	21917.82	75	9595.5	9595.71
26	5994	5994.6	76	0	0
27	1953	1951.88	77	2396	2397.3
28	0	0	78	0	0
29	1715.5	1717	79	0	0
30	0	0	80	1183	1186.02
31	2823.5	2824.09	81	19402	19400.41
32	0	0	82	14943	14942.42
33	34374.5	34498.31	83	17904	17902.65
34	34113	3126.55	84	0	0
35	22209	22242.02	85	2310	2311.14
36	13464	13465.31	86	0	0
37	644	645.72	87	8051	8051.1
38	4604.5	4573.04	88	0	0
39	8993	8991.59	89	77048	77048.88
40	9562.5	9561.22	90	8394	9527.7
41	7982	7981.53	91	0	0
42	7886.5	7886.45	92	2542	2540.28
43	13490.1	13492.78	93	0	0
44	5134	5134.17	94	0	0
45	17532	17858.87	95	16198	14272
46	17352	17351.99	96	18001	17003.43
47	9345.25	9056.66	97	21456	21470.35
48	19106.75	18914.46	98	36865	36868.91
49	19887	19903.41	99	14117	14119.03
50	22412	22414.13	100	12631.5	12631.55

Meter Readings for August, 1990

Account Number	Meter	Metretek	Account Number	Meter	Metretek
1	38147.5	38151.22	51	26943.5	30663.91
2	19707	19711.26	52	58846.5	58846.75
3	39223.5	39222.23	53	35248.25	32511.42
4	27263.4	27265.88	54	38865	38867.17
5	16884.5	16891.93	55	14328	14349.24
6	24693.5	0	56	5008	5008.54
7	8196	8196.53	57	9307	9307.12
8	2324	2323.58	58	51757.75	51759.22
9	14185.75	14187.23	59	9620	9618.94-
10	45116	44954.15	60	22868	22873.38
11	3259	3259.52	61	2443	2443.62
12	9510	9277.05	62	19802.5	19805.09
13	94723	94554.64	63	19580.5	19582.61
14	51881	51881.43	64	36933	36932.15
15	37970.5	37973.28	65	17775	17777.06
16	8529	8532.23	66	38628	38498.79
17	15095	15102.57	67	15334	15346.85
18	3278	3271.73	68	22593.5	22595.99
19	6632.5	6632.29	69	23321.5	23401.8
20	5964.5	5965.28	70	0	0
21	15012	15015.96	71	7467	7466.82
22	43708	72508.91	72	7571	7569.42
23	27427.75	27429.48	73	7431	7429.92
24	40256.5	40261.21	74	4668	4667.74
25	0	0	75	9915.25	9900.66
26	6295.25	6296.27	76	0	0
27	2258.75	2259.87	77	2625.25	2627.45
28	0	0	78	0	0
29	0	0	79	1842	1538
30	41603	40249.68	80	1616	1623.46
31	3033	3033.83	81	23380.25	23378.84
32	0	0	82	17241	17240.8
33	36453.5	36510.88	83	21203.75	21211.84
34	37943	3677.67	84	0	0
35	26046.75	26101.1	85	2558	2561.62
36	15811	15811.51	86	0	0
37	896	900.75	87	8341	8343.15
38	4885	4573.04	88	0	0
39	9333	9333.53	89	81546	81549.39
40	41.5	0	90	8741.75	11852.95
41	8088	8089.15	91	0	0
42	8093	8093.25	92	2841	2840.89
43	16274	16278.67	93	0	0
44	5507	5508.94	94	0	0
45	20598	21238.91	95	19042	14272
46	20392.25	20392.76	96	21148.75	18048.87
47	12389	12431.3	97	25882	25910.71
48	22618	0	98	39973	39980.75
49	24473	24521.06	99	0	0
50	0	0	100	14964.5	14969.46

Meter Readings for October 17, 1990

Account Number	Meter	Metretek	Account Number	Meter	Metretek
1	40544.5	40548.24	51	29213	30601.28
2	22142	22145.27	52	61384	61384.39
3	41264.25	41264.01	53	37121.5	35886.5
4	28685	0	54	40924.5	40927.16
5	18387	18393.27	55	15343.5	15359.32
6	26096	26205.87	56	5255	5182.7
7	8414	8414.36	57	9497	9496.97
8	2496	2495.5	58	54523	54522.87
9	15973.5	15972.32	59	9864.5	9848.13
10	47511.8	47674.08	60	24993.5	24865.48
11	3481	3481.59	61	2673	2674.34
12	9627	9510.3	62	21376.5	21380.69
13	97488	97487.9	63	21264.5	21268.78
14	0	0	64	38677	38678.65
15	40917	40923.26	65	19242.5	19243.41
16	8739	8740.74	66	40463.5	40464.14
17	16413	16421.61	67	0	0
18	3398.5	3398.31	68	24423.5	24427.31
19	6825	6826.95	69	25572	25624.85
20	6091	6090.48	70	0	0
21	16833	16842.39	71	7693.5	7685.28
22	45741.5	45740.12	72	7764.5	7766.29
23	30085.5	30087.72	73	7738	7742.77
24	42874	42880.14	74	4855	4855.1
25	27668.6	27684.73	75	52.5	51.16
26	6518.25	6519.65	76	0	0
27	2385	2385.79	77	2762.5	2761.35
28	0	0	78	0	0
29	6022	6022.89	79	1986	1986.31
30	43477	43477.52	80	1848	1851
31	3172.75	3172.01	81	25386	25385.99
32	0	0	82	18552	18551.71
33	37633.5	37698.81	83	22374.5	22385.59
34	39961	39961.23	84	0	0
35	28274	28307.98	85	2735	2736.22
36	17147	17150.2	86	0	0
37	1036	1038.04	87	8500.5	8501.91
38	5046	5047.72	88	244	244.04
39	9492	9492.28	89	84121.5	84124.47
40	247.5	247.3	90	8986.5	8988.69
41	8183	8182.58	91	0	0
42	8216	8216.22	92	3050.5	3032.64
43	17633	16810.47	93	0	0
44	5638	5637.92	94	0	0
45	22591	23239.25	95	21032	21031.64
46	21853.5	21855.66	96	22661	21751.61
47	13840.5	13852.83	97	27941	27959.77
48	24532.5	23374.22	98	42005.5	42018.64
49	27077	27110.07	99	0	0
50	24417.5	24423.65	100	16332.6	16337.96

Meter Readings for November 14, 1990

Account Number	Meter	Metretek	Account Number	Meter	Metretek
1	42614	42617.45	51	1641.5	29771.57
2	24234	24239.48	52	63631	63630.36
3	42653	42651.59	53	1941	37121.5
4	28803.5	28804.37	54	42383	42387.11
5	19103.5	19111.11	55	15756	15766.42
6	27412	27723.12	56	5363	5256.95
7	8577	8577.54	57	9610	9610.6
8	2567	2567.08	58	56763	56763.22
9	16696.5	16696.5	59	72	55.26
10	49273.5	49272.34	60	26196	26112.37
11	3661	3662.59	61	2826	2706.42
12	9681	9627.13	62	22147	22151.88
13	99466.5	99466.9	63	21937	21941.33
14	0	0	64	40031	40031.95
15	43067.5	43077.36	65	19918.5	19920.86
16	8914	8916.96	66	42013	41921.56
17	16982	16993.58	67	0	0
18	3463	3461.3	68	25313	25315.72
19	7050	7053.57	69	26591	26552.56
20	6143.5	6144.76	70	0	0
21	17918.5	17925.41	71	7918	7918.56
22	47763.5	47762.67	72	7846	7841.98
23	30085.5	30087.72	73	8015	8028.7
24	45111.5	45117.9	74	4933	4932.89
25	28973.5	28972.8	75	122	120.83
26	6732	6731.79	76	0	0
27	2440.5	2440.3	77	2902.5	2902.58
28	0	0	78	0	0
29	7472	7472.32	79	2170	2169.85
30	44318	44318.84	80	1995	1988.14
31	3311	3310.21	81	26479	26479.09
32	0	0	82	19237	19237.79
33	39084	39222.25	83	22801	22810.31
34	41333.5	41334.27	84	0	0
35	29965.5	30098.83	85	2894	2895.77
36	18292.5	18296.51	86	0	0
37	1097	1097.72	87	8566	8568.06
38	5136	5132.26	88	335	335
39	9565	9563.9	89	85463.5	85467.63
40	313	311.75	90	9196	9196.37
41	8303.5	8295.5	91	0	0
42	8331	8329.92	92	3266.5	3268.12
43	18312	17709.75	93	0	0
44	5691	5690.63	94	0	0
45	23608	24217.04	95	22842	22742.44
46	22898	22900.67	96	23393.5	22661.29
47	14270.5	14246.36	97	28815	28825.95
48	25374.5	25375.76	98	43703.5	43708.15
49	28221.5	28236.63	99	0	0
50	25463	25469.45	100	16927.5	16934.84

ABBREVIATIONS AND ACRONYMS

AMR	automatic meter reading (system)
ANSI	American National Standards Institute
DEH	Directorate of Engineering and Housing
DOD	Department of Defense
ES	Energy and Utility Systems Division (USACERL)
ETL	Engineer Technical Letter
FEAP	Facilities Engineering Applications Program
Mb	megabyte
PC	personal computer
PROM	programmable read-only memory
RAM	random access memory
RMU	residential metering unit
SMOD	smart modem
TNI	telephone network interface
USACERL	U.S. Army Construction Engineering Research Laboratories
USAEHSC	U.S. Army Engineering and Housing Support Center

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